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PHOSPHATE REDUCTION FOR LIMITING ALGAE GROWTH IN LAKES OF RENOVATED WASTEWATER

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PHOSPHATE REDUCTION FOR LIMITING ALGAE GROWTH IN LAKES OF RENOVATED WASTEWATER*

By

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and

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PHOSPHATE REDUCTION FOR LIMITING ALGAE GROWTH IN LAKES OF RENOVATED WASTEWATER

I. Introduction

A. Background

Lancaster, California, is a rural community of about 35,000 on the southern edge of the Mojave Desert about 80 miles northeast of Los Angeles. For over 20 years the wastewater of the area has been given primary treatment followed by biological stabilization in oxidation ponds. Presently, 3 million gallons per day (MGD) are treated and then lost to the atmosphere by evaporation. With annual rainfall of only 2 to 3 inches, the area depends on underground sources for both irrigation and domestic water supplies. Supplemental water will eventually be imported from Northern California; in the interim, ground water must be conserved for domestic, industrial, and irrigational purposes. In recognizing the community's need for water-based recreational facilities, the Los Angeles County Engineer proposed converting an existing borrow pit to an aquatic park featuring three lakes with a combined surface area of 19 acres.

The Sanitation Districts of Los Angeles County joined with the Advanced Waste Treatment Branch of the Federal Water Pollution Control Administration, Department of the Interior (formerly the U. S. Public Health Service) in a research effort to investigate the best possible methods of renovating the oxidation pond water to a point where it would be suitable for use in the lakes. Since oxidation ponds are used in many arid areas, it was hoped that the techniques developed in Lancaster would be applicable to other localities.

The water in the oxidation ponds is unsuitable for use in the lakes without further treatment. The green algae which abound in the oxidation ponds supply oxygen to the bacteria which decompose the organic matter in the wastewater. However, since algae receive their energy from light they photosynthesize and produce oxygen only during daylight hours. The water becomes supersaturated with dissolved oxygen with maximum concentrations as high as 40 milligrams per liter (mg/l) in Lancaster. The bacteria, however, utilize oxygen continuously and can reduce the dissolved oxygen of the water to as low as 1 mg/l or less. Fish cannot survive in such an extreme environment, a fact confirmed by previous attempts to raise carp in the oxidation ponds.

In addition to sunlight, algae require carbon, nitrogen, phosphorus and certain trace elements to live. The carbon is obtained from carbon dioxide and bicarbonate in the water, raising the pH to between 8.5 and 9.5, which is a difficult range for fish. It was concluded that both the bacterial and algal populations in the oxidation pond water would have to be drastically reduced if the water were to be suitable for use in recreational lakes. The bacterial population could be reduced by either reducing their food supply or the organic matter and algae in the water. However, a new cycle of algae growth, organic matter production and bacterial decomposition was sure to start unless one of the essential algal nutrients was also removed. The only essential nutrient that offered any hope of removal to growth limiting concentrations was phosphorus and its removal became a major objective of the study.

B. Research Objective

The immediate study objective was to determine and pilot the most economical method of renovating the wastewater for use in the recreational lakes. However, the lack of recognized limiting quality criteria for recreational lake water required that arbitrary criteria be established as contingent objectives in evaluating processes. It was recognized that these criteria might need to be revised as the study revealed cost data, process capabilities and renovated water behavior.

Reviews of the literature (1,2) and consultation with algologists at the Robert A. Taft Sanitary Engineering Center and the recent experience of the Santee County Water District with recreational lakes supplied by soil-filtered wastewater near San Diego (3), provided the basis for the following initial quality objectives:

1. Turbidity of less than 10 Jackson Turbidity Units (JTU).
2. Phosphate concentration of less than 2 mg/l as PO_4.
3. pH of less than 8.0
4. Low concentration of chemical oxygen demand (COD), and biological oxygen demand (BOD).
5. Algae counts less than 10,000 per milliliter.
6. Coliform and virus determinations to meet requirements of the County Health Officer.

Subsequent experience has resulted in the revision of the phosphate objective from 2 mg/l to 0.5 mg/l or less. The other criteria are still considered adequate. Product water, or water produced by the selected

process, is generally of better quality than would be indicated by these objectives. The turbidity objective of 10 JTU, for example, is double the average turbidity of the product water; the final turbidity is a consequence of the chemical dosage required for phosphate removal. The low turbidity makes the water clear and sparkling which will increase its public acceptance as it enters the lake.

C. Facilities

Project site, facilities, and oxidation pond flow pattern are shown in Figure 1. The District 14 Water Renovation Plant features primary sedimentation followed by 240 acres of oxidation ponds. Each of the eight ponds has a surface area of about 30 acres and 5- to 7-foot water depth. Only the first four ponds are considered to be in the treatment series; the last four are used for winter storage when evaporation rates are low and are dried out in the summer to inhibit midge propagation.

Primary effluent is divided equally between ponds 1 and 2 and dispersed through 400-ft. diffusers to avoid overloading a portion of the pond. Pond 1 discharges into pond 2; the combined flow then passes sequentially through ponds 4, 3, and 5 as shown. The flow pattern can be varied as desired. The average residence time to the discharge of pond 3 is between 45 and 60 days. Pond 3 is the designated source for water to be used in the recreational lakes and was the source for all water treatment studies conducted in this project.

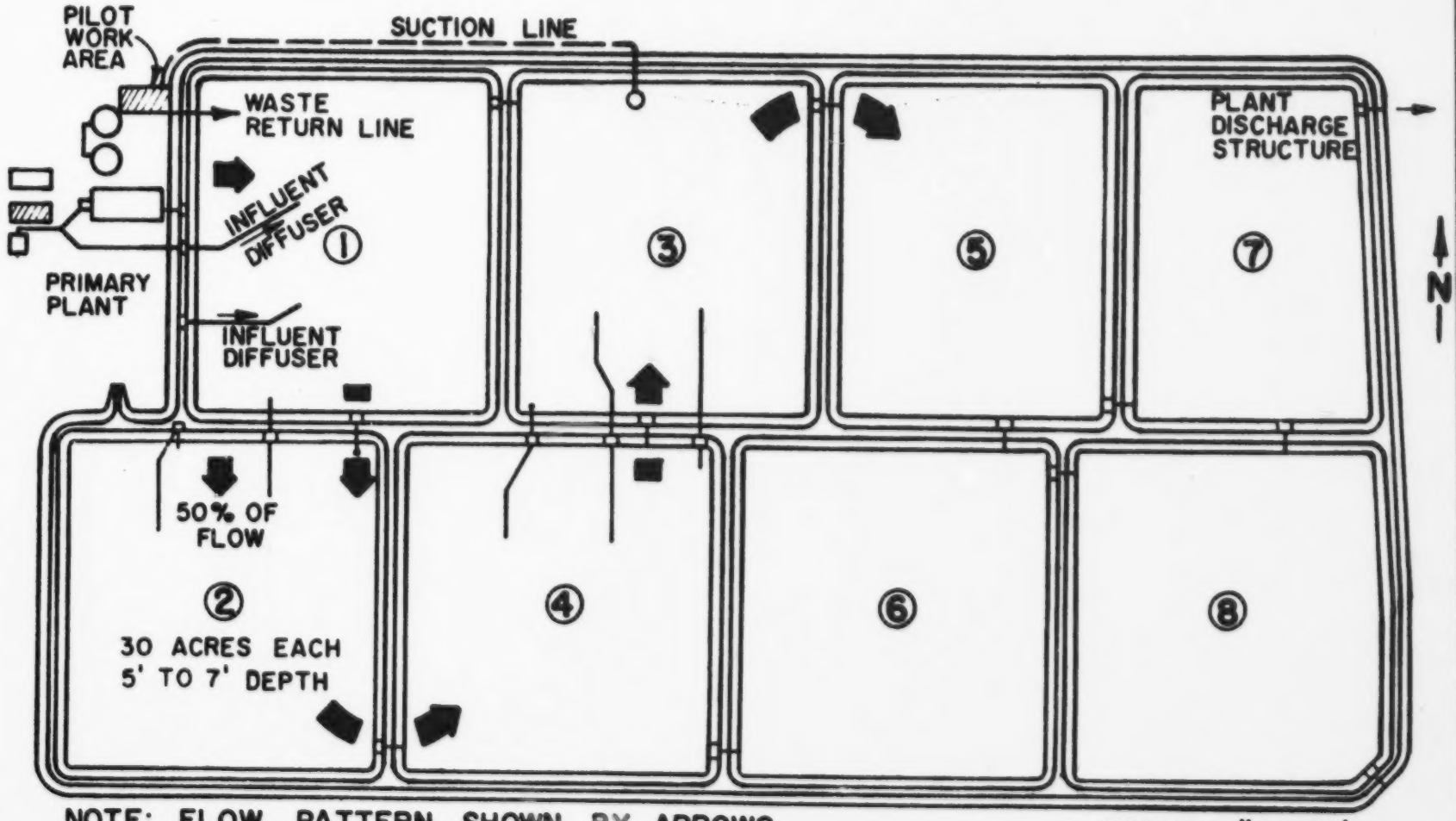


FIGURE 1

OXIDATION PONDS AND STUDY AREA

D. Project Work Plan

The project was conducted in two phases: (a) Phase I was directed toward determining the most effective and economical process for renovation of the wastewater (b) Phase II consisted of operating the chosen process and evaluating the product water in simulated recreational lakes.

II. Phase I Studies

To accomplish the desired objectives in a minimum of time, three research steps that would normally be conducted successively were performed concurrently. They were:

1. The collection of basic data on the character of the water to be treated.
2. Laboratory jar test evaluations of various coagulants to determine the most feasible chemical treatment and the optimum conditions for removing algae, other suspended material, and nutrients.
3. Pilot-plant process evaluation of promising processes to develop cost and performance data in order to select preferred processes for renovating the wastewater.

A. Characteristics of the Wastewater

Analyses of the plant primary effluent and of the oxidation pond water commenced in October 1963. Grab samples from the pond were collected and analyzed for selected chemicals and algae genera and numbers. An automatic sampler was installed on the primary effluent in July 1964, to obtain

more representative data. The average characteristics of the primary effluent are:

pH	7.2
Total alkalinity	258 mg/1
Phosphate	45 mg/1
Ammonia-nitrogen	27 mg/1
COD	392 mg/1
Suspended solids	90 mg/1
Dissolved solids	553 mg/1
Organic nitrogen	11 mg/1
Nitrate-nitrogen	0.1 mg/1
Nitrite-nitrogen less than	0.01 mg/1

Pond-wide sampling established that the long detention times within the ponds and frequent strong winds resulted in excellent mixing and averaging of most chemical constituents at any given time.

In the course of the study it was observed that, to accomplish equivalent results, greater chemical doses were required during the winter and spring period of high total alkalinity, phosphate, and ammonia than during the summer and fall period when lower values prevailed. Essentially all chemical changes in pond 3 were traced to either physical factors such as sunlight intensity, temperature, and wind mixing, or biological factors such as specie composition of the biomass, the metabolic rates of the algae and bacteria, and the growth of crustaceans.

The cyclic patterns of ammonia and total phosphate in pond 3 water are shown in Figure 2. The ammonia concentration is less than 3 mg/1 during the summer and fall and then increases to about 20 mg/1 for much of the winter and spring. The seasonal decrease of ammonia by biological synthesis represents most of the nitrogen removal that is accomplished in the oxidation ponds. The low ammonia levels in the summer correlate with

PHOSPHATE AND AMMONIA - POND NO. 3

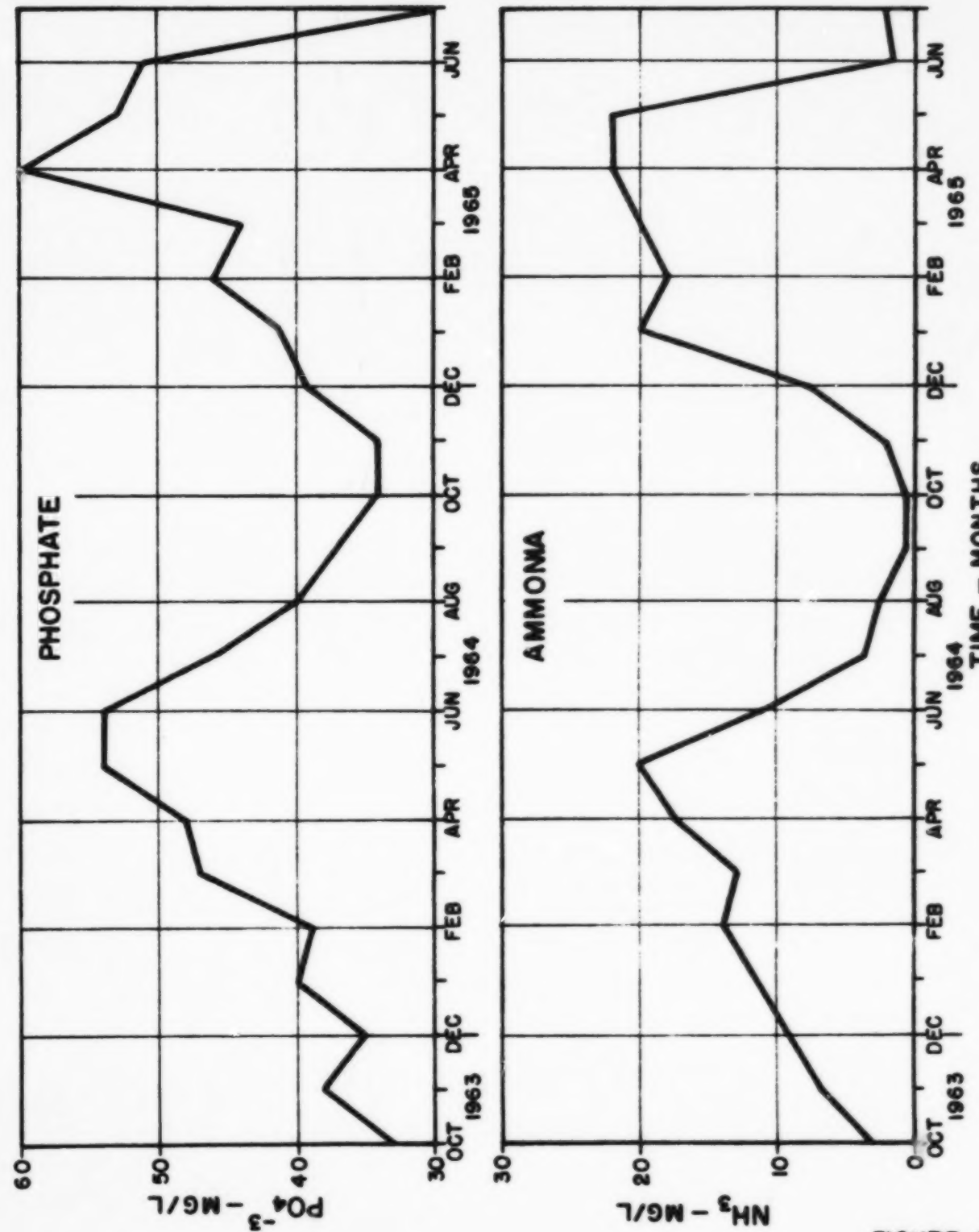


FIGURE 2

the period of rapid metabolism; the high levels in the winter correspond to the period when low sunlight intensity and low temperatures reduce the rate of photosynthesis. Nitrate and nitrite concentrations are generally low throughout the year; however, in the spring of 1966 as temperatures were rising, nitrite values reached 10 mg/l for about a week before the development of nitrate-producing bacteria which converted the nitrite to nitrate. Organic nitrogen has been observed as high as 20 mg/l coinciding with high algal counts.

The ammonia variations are also accompanied by similar changes in the total alkalinity which averages 260 mg/l in the winter and spring and 220 mg/l in the summer and fall. The higher alkalinity and ammonia concentrations, which tend to buffer pH changes, and the lower temperature, which reduces chemical reaction rates, require that additional coagulants be used for equivalent treatment.

The total phosphate concentration is also higher during the winter and spring than in the summer and fall period. Biological synthesis, sedimentation of algae and possibly calcium phosphate precipitation at the higher pH values of the summer and fall all contribute to lowering total phosphate levels. The low total phosphate concentrations permit low coagulant dosages for equivalent residuals.

Other periodic variations between the colder and warmer seasons which are important to the tertiary process include: (a) temperature, which varies from 6 to 30°C; (b) pH, which ranges from 7.5 to 9.6; (c) chemical oxygen demand, which decreases from 300 to approximately 200 mg/l;

(d) biological oxygen demand, which decreases from 50 to 40 mg/l; (e) suspended solids, which decrease from 100 to 75 mg/l; (f) dissolved solids, which decrease from 640 to 570 mg/l; and (g) turbidity, which ranges from 90 to 170 JTU in the cold season and from 40 to 150 JTU in the warm season.

The oxidation ponds contain about 66 algae genera in varying concentrations (50,000 to 700,000 counts/ml) throughout the year. Scenedesmus is the most common, although Euglena, Ankistrodesmus, Phacus, Oocystis, Chlorella and Nitzschia have also been dominant.

The most common crustaceans found at random in the oxidation ponds at different times are Daphnia and Cyclops. These algae predators contribute to the variation in algae counts and algae genera.

The oxidation ponds are very effective in reducing both bacteria and virus levels. The bacteria reductions, after 45 to 60 days detention were in excess of 99.7% (Figure 3). Viruses were detected in 96% of primary effluent samples and in only 8% of the pond 3 samples. Polioviruses I, II and III, the adeno group, coxsackievirus B-3, echovirus 7 and reovirus have been identified in the primary effluents. In oxidation pond 3 wastewater, one sample contained polio II and three samples contained an unidenitified virus.

B. Laboratory Studies

Laboratory studies included jar test evaluation of coagulants. The object was to determine the most effective coagulants and coagulant aids, their required dosages, the best flocculating conditions, and relative costs.

MEDIAN BACTERIA COUNTS THROUGH OXIDATION PONDS

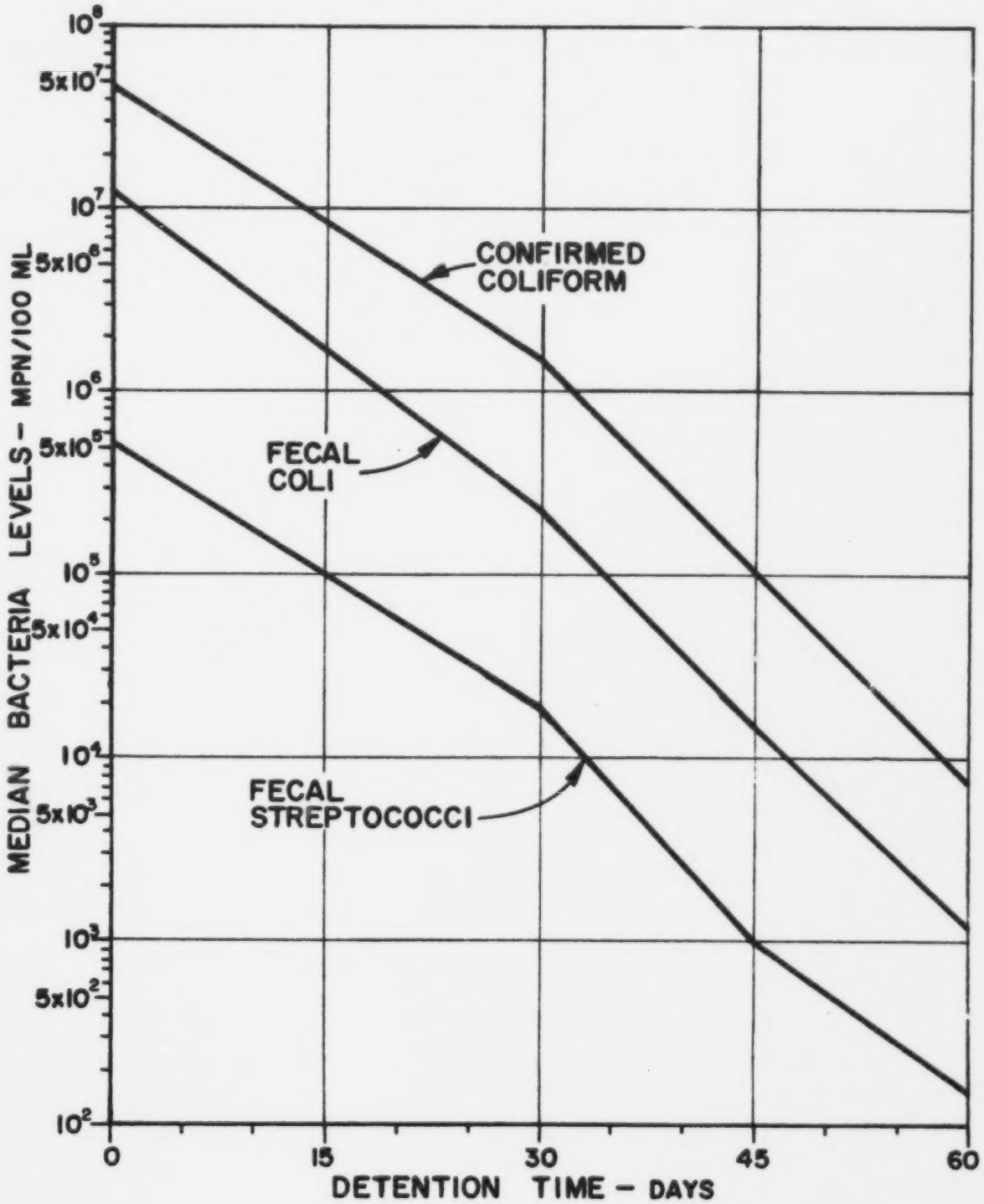


FIGURE 3

The jar test apparatus consisted of a 10-place stirrer equipped with a variable speed paddle drive. All tests were performed on water from oxidation pond 3 following the procedures suggested by Cohen (4).

To facilitate screening a maximum number of samples, the effectiveness was rapidly estimated by a turbidity measurement. Additional chemical analyses were performed on particularly promising samples.

The number of coagulant combinations tested are too numerous to report. The major coagulants were:

1. Aluminum sulfate, $AL_2(SO_4) \cdot 14H_2O$, (commercial grade-alum) with and without pH adjustments and other coagulant aids.
2. Calcium hydroxide - $Ca(OH)_2$ (lime) both hi-calcium (90% $Ca(OH)_2$) and the less expensive dolomite (58% $Ca(OH)_2$ and 41% $Mg(OH)_2$).
3. Ferric sulfate - $Fe_2(SO_4)_3$, 70% pure, 30% inert.
4. Dow C-31 cationic polyelectrolyte, (Dow NC1118, UCAR-149 and Nalco 600 cationic polyelectrolytes were also tested. Dow C-31 test results were very similar to the other three cationic polyelectrolytes).
5. Sulfuric acid - H_2SO_4 (66° Baume).

The results of the jar test studies for the primary coagulants in relation to costs are presented in Figure 4. Dolomitic lime was used in the cost analyses even though hi-calcium lime was actually used in pilot studies because it was easier to handle. The jar test showed the two

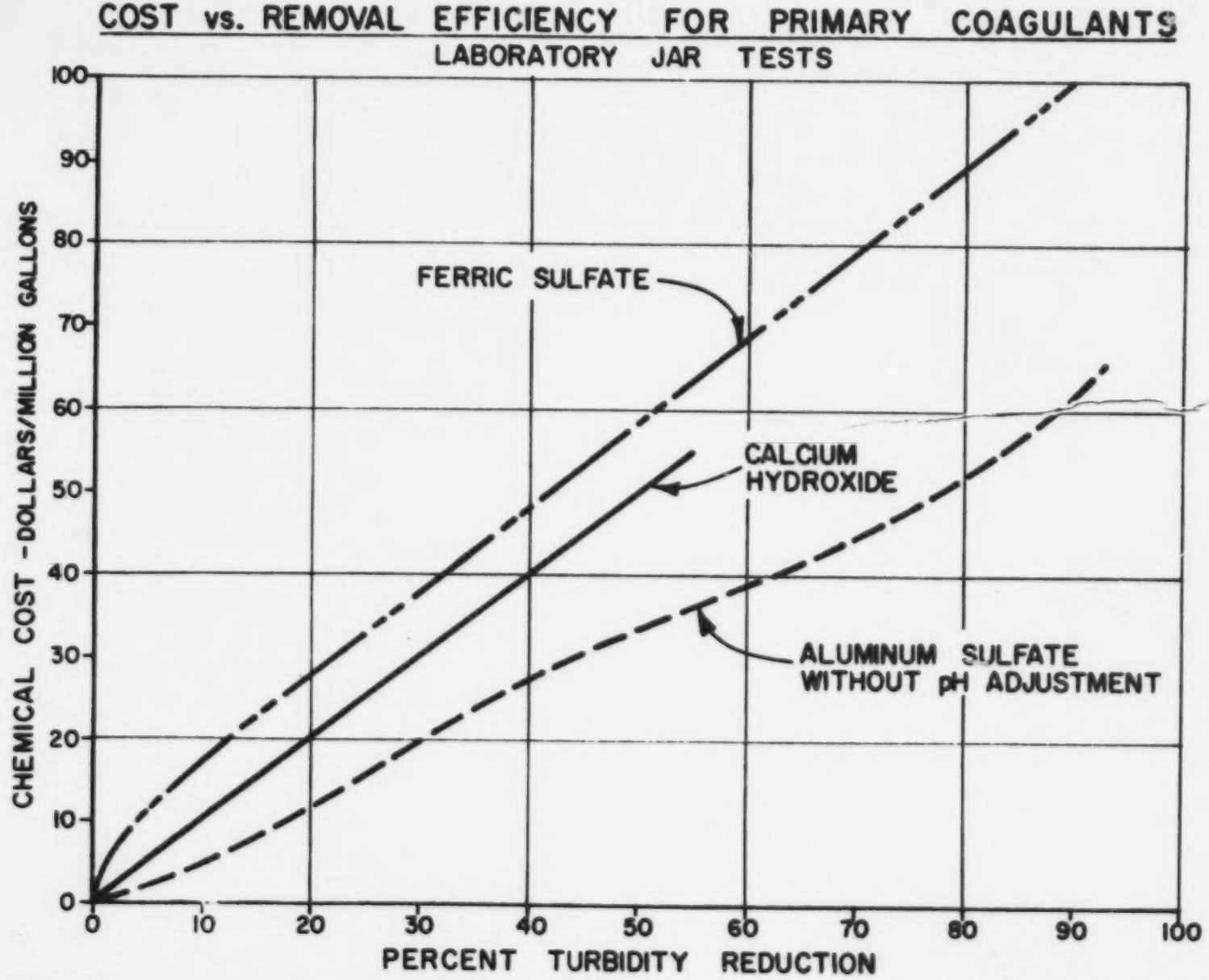

COST vs. REMOVAL EFFICIENCY FOR PRIMARY COAGULANTS
LABORATORY JAR TESTS
CHEMICAL COST - DOLLARS/MILLION GALLONS
PERCENT TURBIDITY REDUCTION
FERRIC SULFATE
CALCIUM HYDROXIDE
ALUMINUM SULFATE WITHOUT pH ADJUSTMENT
0
10
20
30
40
50
60
70
80
90
100

FIGURE 4

9-14

products to be equally effective at equivalent dosages. Ferric sulfate was omitted from further primary coagulant studies due to its higher cost.

The majority of the jar tests were conducted with alum, lime, and various cationic polyelectrolytes as coagulants. In addition, sulfuric acid and carbon dioxide were used for pH adjustment in conjunction with alum coagulation.

Test results for primary coagulants and coagulant combinations and their costs are shown in Figure 5 which include the over-all effect of levels of chemical constituents in pond 3.

Figure 6 shows the effectiveness and costs of coagulant combinations during periods when the difference in chemical requirements is related to changes in the characteristics of pond 3 water previously described. Lime was less effective in the spring period whereas it was competitive with alum in the fall. Figure 7 compares alum and lime coagulation for total phosphate removal. In the colder season alum coagulation was much more successful for reducing phosphate concentrations. With lime coagulation, a substantial colloidal precipitate remained which could account for the higher phosphate residual.

The use of cationic polyelectrolytes, or acid for pH adjustments, materially reduced the quantities of alum required to accomplish turbidity objectives in each seasonal period although the coagulant cost in the spring was much higher than in the fall. However, the cationic polyelectrolytes and sulfuric acid do not remove soluble phosphate. Consequently, alum in combination with acid or polyelectrolytes is not as effective in removing phosphate as

COST vs. FINAL TURBIDITY FOR DIFFERENT COAGULANTS

LABORATORY JAR TESTS

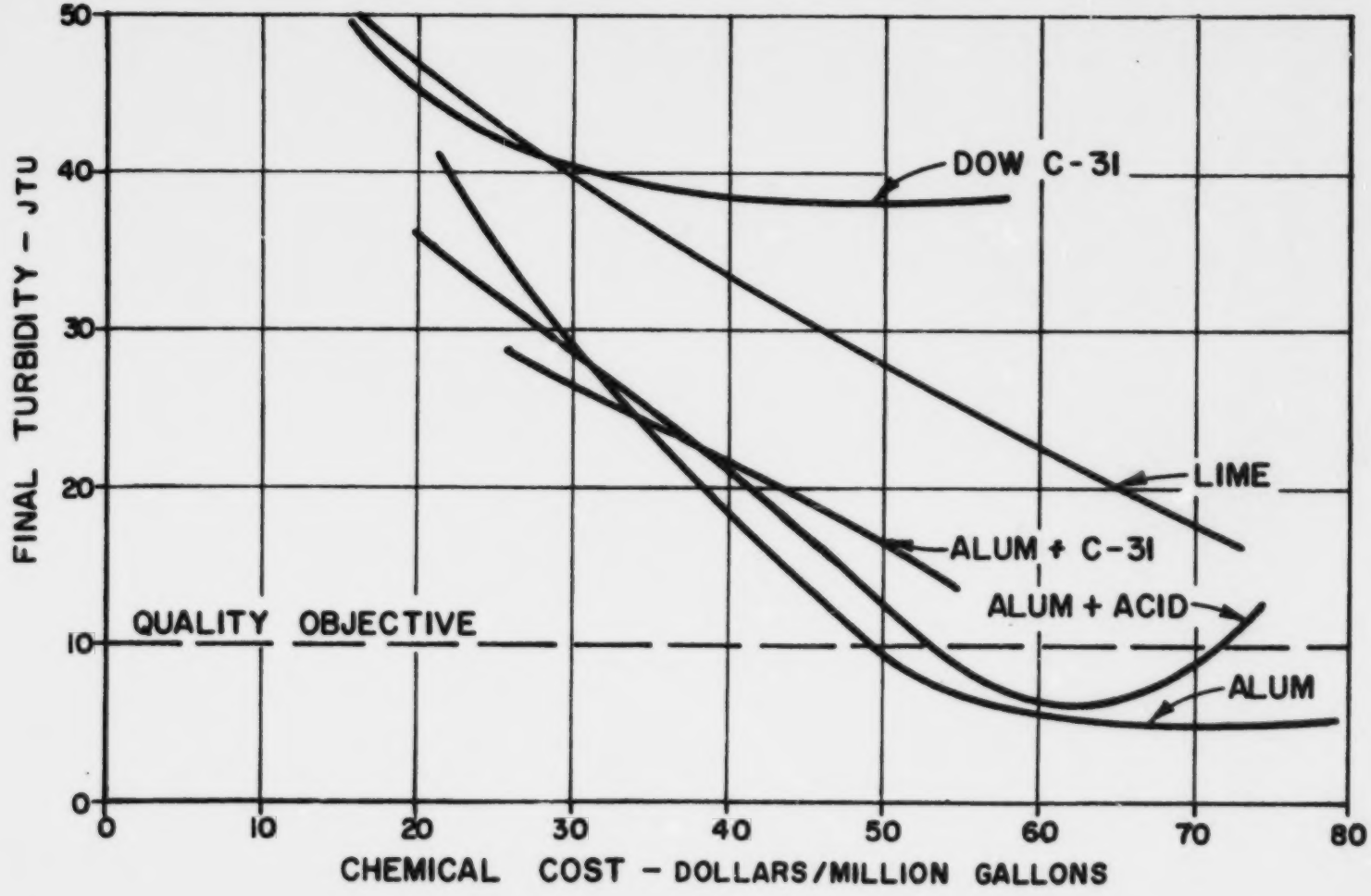
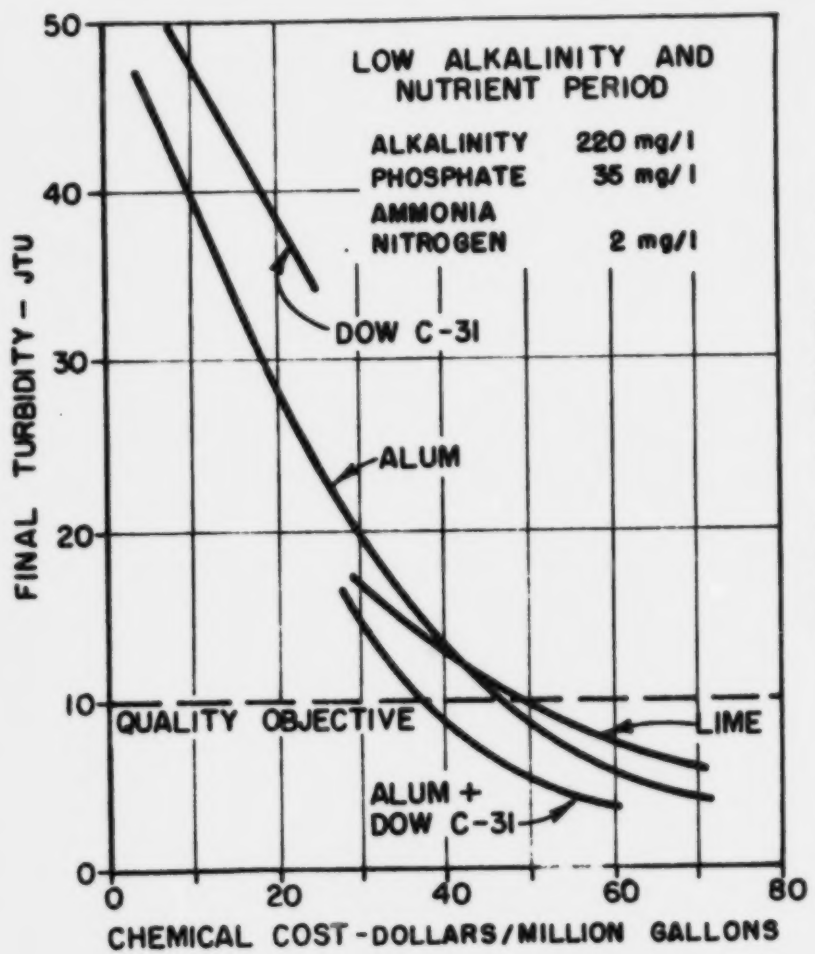


FIGURE 5

COST vs. FINAL TURBIDITY FOR DIFFERENT COAGULANTS DURING HIGH AND LOW ALKALINITY AND NUTRIENT PERIOD

LABORATORY JAR TESTS



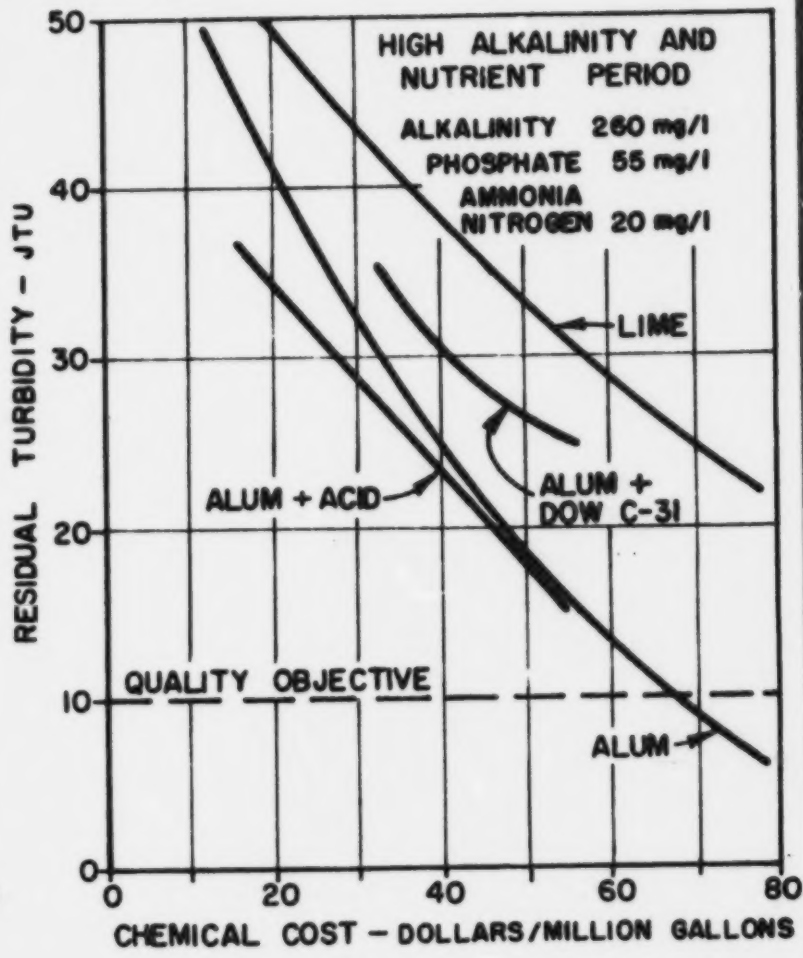


FIGURE 6

RESIDUAL PHOSPHATE FOR ALUM AND LIME COAGULATION

LABORATORY JAR TESTS

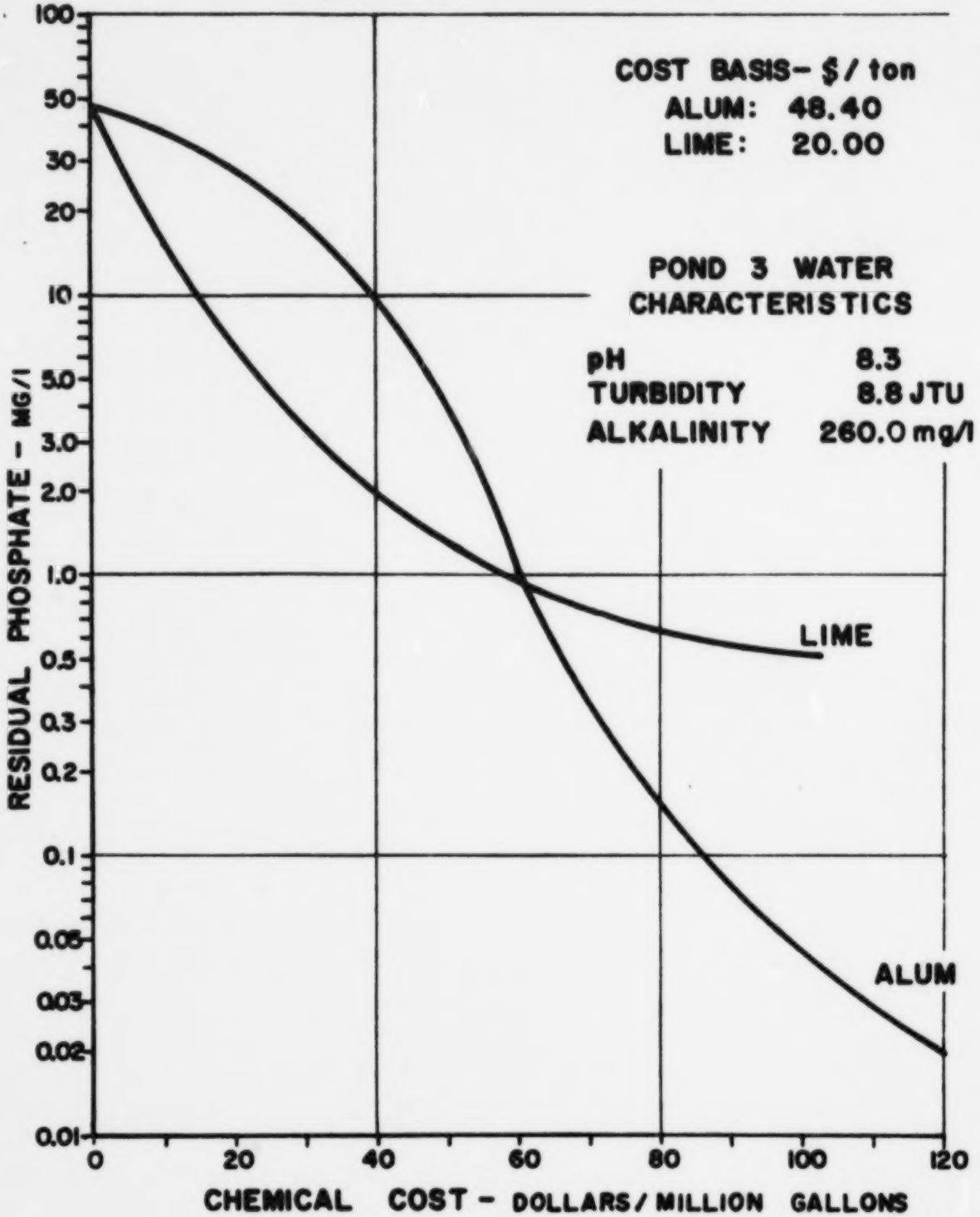


FIGURE 7

the larger dosage of alum alone. Since alum was the most effective coagulant, it received the most attention in pilot work.

Jar test studies were also used to determine optimum conditions for successful alum coagulation of pond 3 water for phosphate removal. These studies showed that with or without the addition of acid and base to change the initial pH and alkalinity, phosphate residuals were minimum when the final pH was approximately 6.0 - Figure 8. Increasing the alum dosage from 150 to 300 mg/l also decreased the minimum phosphate residual. Others have found that the equilibrium constant for alum indicated phosphate can be removed to 0.04 mg/l and that the pH for optimum removal is close to 6.0.

C. Pilot Plant Process Evaluation

The pilot plant studies were designed to evaluate and compare various treatment processes and to obtain reasonable cost estimates. The pilot area was arranged around a central run of influent and effluent piping with connections for six concurrent processes. Oxidation pond water was delivered to the pilot area from mid-depth on the north side of pond 3 through a 1600-ft., 6-in. diameter pipeline and waste and product water were pumped back into pond 1. Pilot units ranged in capacity from 1 to 50 gallons per minute (GPM).

Initially, experiments were conducted to remove algae separately from the dissolved nutrients in the hope of producing a marketable algae for use as a poultry feed. A small microstrainer (23-micron screen), a

PHOSPHATE RESIDUAL vs. pH

LABORATORY JAR TESTS

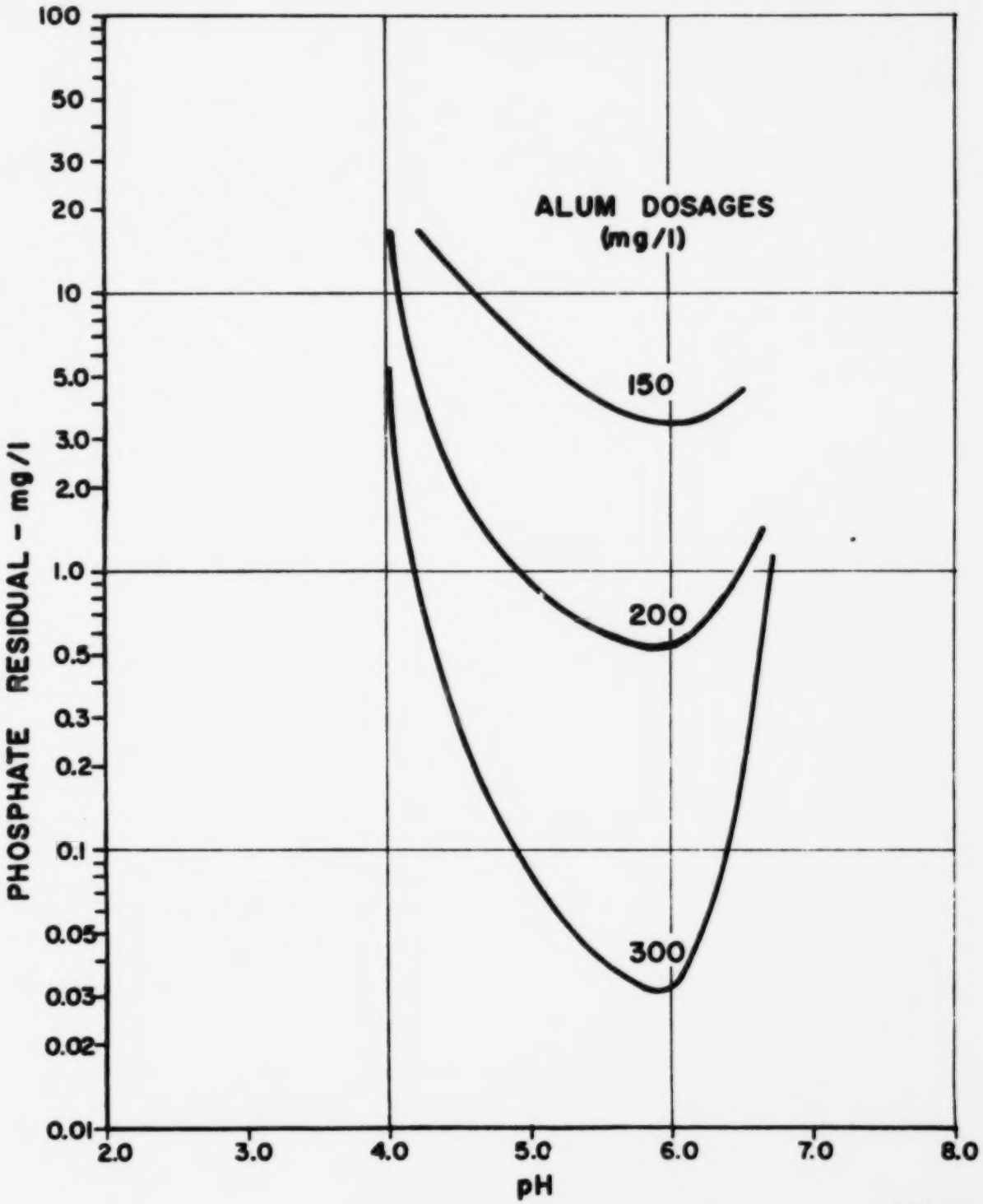


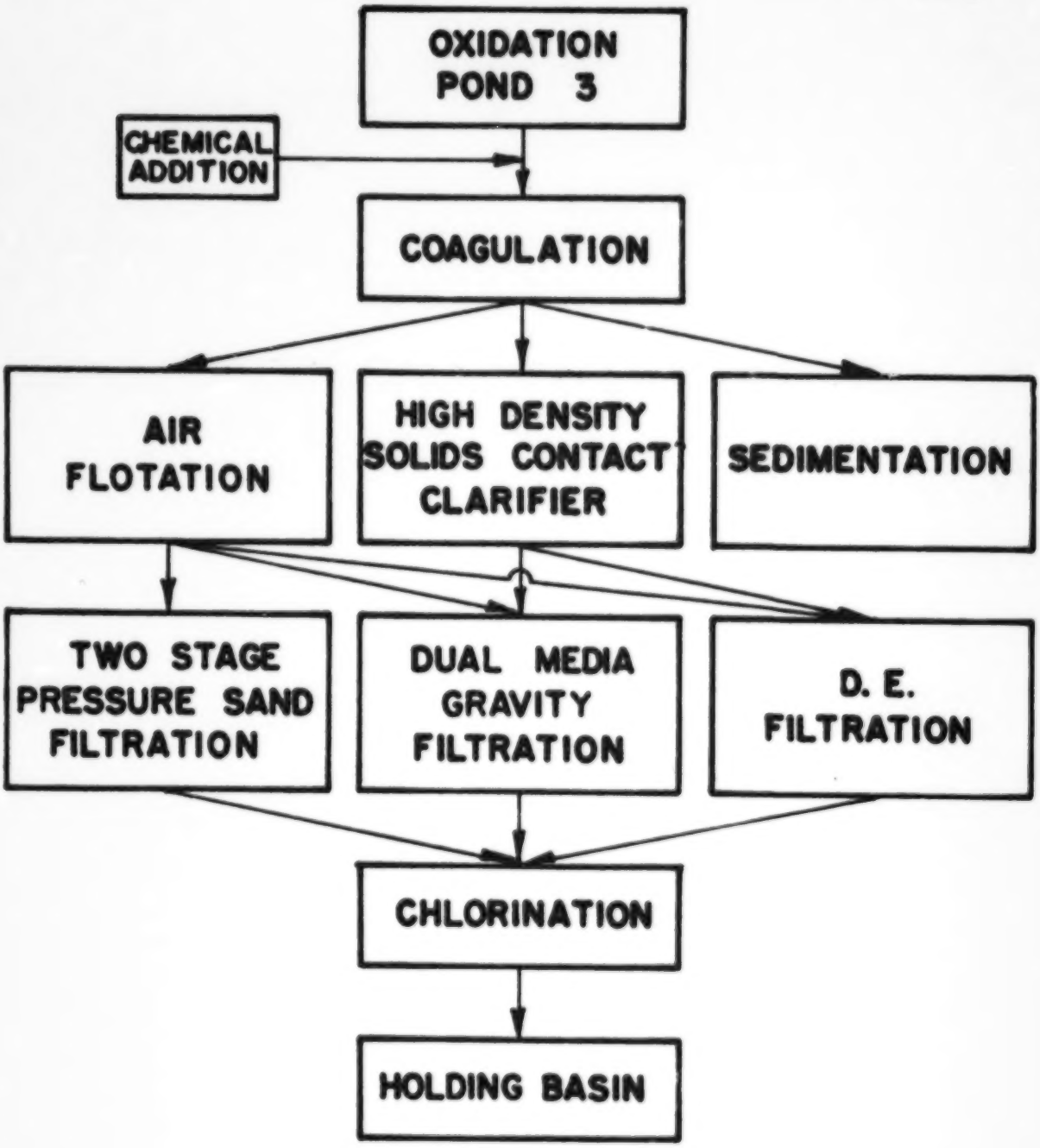
FIGURE 8

pressure sand filter and three types of diatomaceous earth (DE) filters were tested. These processes failed to produce the desired results. Removals with the microstrainer were totally inadequate and blinding by the bodies of crustacea and other foreign material occurred quite rapidly. The pressure sand filter removed a good percentage of the algae but not enough to be economical. The DE was quite successful in removing the algae although color and turbidity of the product water were still high. The estimated value of the recovered algae was $25.00 per million gallons (based on $100/ton) but the process costs for short filter cycles, separating the algae from the cake and drying it far exceeded the product value. More recent evaluations by Dr. William Oswald (personal communication) at the Davis Campus of the University of California have shown some algae to be a substitute for fish meal valued at $200 per ton.

The study, thereafter, concentrated on the best possible processes for clarifying the water. In spite of the potential savings to be gained by completely removing turbidity and dissolved nutrients in a single process, preliminary pilot work indicated that a combination of processes would be required to achieve the desired quality objectives. The first process would materially reduce suspended matter and nutrients by chemical treatment and the water then would be polished by filtration and disinfected by chlorination. Figure 9 shows the sequence of process steps tested.

D. Chemical Processes

Initially the quality objectives for the chemical processes were a turbidity of 20 JTU or less and total phosphate concentration of less than 2 mg/l. Subsequent algal regrowth studies emphasized the need to reduce total phosphate levels to less than 0.5 mg/l by using larger dosages



PILOT PLANT FLOW SHEET
PHASE I

FIGURE 9

of alum, which also reduced turbidity levels to the 5- to 10-JTU range. Turbidity was used to compare the relative effectiveness of the pilot processes in screening tests because of the ease and rapidity of measurement. The following types of pilot equipment were tested:

1. Portable Water Treatment Plant - A completely self-contained trailer-mounted water purification unit of 25 GPM rated capacity loaned to the project by the U. S. Army. It featured an upflow clarifier with a central mixing and flocculating chamber. Results were not satisfactory because of the release of supersaturated dissolved oxygen and other gases which bouyed the floc to the surface.

2. High Density Solids Contact Clarifier - A complete lime-coagulation and recarbonation water treatment unit of 25 GPM capacity with provision for sludge recycle and auxiliary chemical addition. The first of two 10-ft. high, 4-ft. diameter vertical columns contains rapid mix, coagulation and flocculation zones near the top with upflow clarifier and sludge collection zones in the bottom. The second column or recarbonator contains inverted trays to adjust pH by adding CO_2 and a chamber for supplementary settling and sludge recycle. The unit did not operate successfully at its rated capacity but was adequate at 10 to 15 GPM.

3. Dissolved Air Flotation - Pilot units in two sizes were used in this study:

   a. One square foot air flotation unit - rated capacity of 0.3 to 3.0 GPM, air dissolved into auxiliary water stream at 60 to 70 pounds per square inch (psi), manually skimmed, operated at about 1 GPM.

   b. A 6-ft. diameter, 27-ft.^{2}, 6-ft. deep, air flotation unit rated at 50 GPM capacity. Coagulated water entered a supersaturated mixing chamber in the center of the 6-ft. high tank. Air dissolved into the recycle water is released in small bubbles that lift the floc to the top where it is skimmed into a trough. The clarified water flows to the bottom of the tank and up to and over a circular weir around its periphery. The unit was operated at flow rates between 20 and 50 GPM with most runs at 30 or 40 GPM. The recycle stream was varied from 10 to 25 GPM at pressures of 40 and 20 psi, respectively. Air at about 15 CFH was introduced by eduction into the suction of the recycle pump.

4. Sedimentation - A 1500-gallon circular tank, 4-ft. deep and 7.5-ft. diameter, was baffled to serve for a brief trial of horizontal-flow sedimentation. At 11 GPM there was a 2-hour detention time and an overflow rate of 340 GPD/ft^2. A submerged discharge protected the effluent from floating algae. It was sufficiently effective to justify construction of a larger unit.

The high density solids contact clarifier, air flotation and sedimentation processes were technically feasible. The sedimentation tank test results were almost identical to those obtained in the air flotation unit in contrast to the very poor results obtained in the truck-mounted upflow clarifier used in the early part of the study. The pilot-plant tests substantiated the jar tests results in that alum remained the most effective chemical coagulant. Thus both air flotation and horizontal sedimentation with alum as primary coagulant were chosen as the preferred processes to be evaluated in Phase II.

5. Filtration Processes - Polishing of primary process effluent by filtration provides a safety factor and produces a water of such clarity that its appearance will be pleasing to the public. The following types of equipment were tested:

   a. Diatomaceous Earth Filters

      1. A low pressure reversible cake DE filter of 0.5 to 3 GPM capacity, operated at approximately 1 GPM for pilot tests.
      2. A truck-mounted 25-ft.^{2} pressure filter.
      3. A wound-wire pressure filter.
      4. A vertical leaf swimming pool pressure filter.
      5. A 1-ft.^{2} bench-scale pressure filter.
      6. A 50-ft.^{2} tube and shell pressure filter.

   b. Sand Filters

      1. A two-stage pressure sand filter of 2-ft. depth and 2.2 ft.^{2} surface area per stage.

2. Six 3-1/2 in. diameter, 0.06 ft.^{2} lucite gravity sand and dual media filter columns.
3. A 12 ft.^{2} gravity sand or dual media (anthrafilt-sand filter).

Diatomaceous earth filter effluents were consistently better than effluents from the dual media or pressure sand filters. However, DE filter cycles did not exceed 3 hours, resulting in excessive DE usage and high costs estimated between $80.00 and $200.00 per million gallons. The short filter cycles were caused by blinding of the filter by algae and other particulate matter not removed in the previous separation process. The compressibility of the gelatinous floc contributed to the rapid blinding in spite of DE body feed rates of up to 90 mg/l and influent water turbidities as low as 3 JTU.

Pressure sand and dual media filtration both reduced influent turbidities by 25 to 50% resulting in filter effluents with turbidities of 10 JTU or less when the effluent turbidity from the chemical process was between 10 and 20 JTU. Longer operating cycles and the reuse of the filter media provided a substantial cost advantage for sand and dual media filter over the DE units.

III. Phase II - Final Evaluation of the Preferred Processes

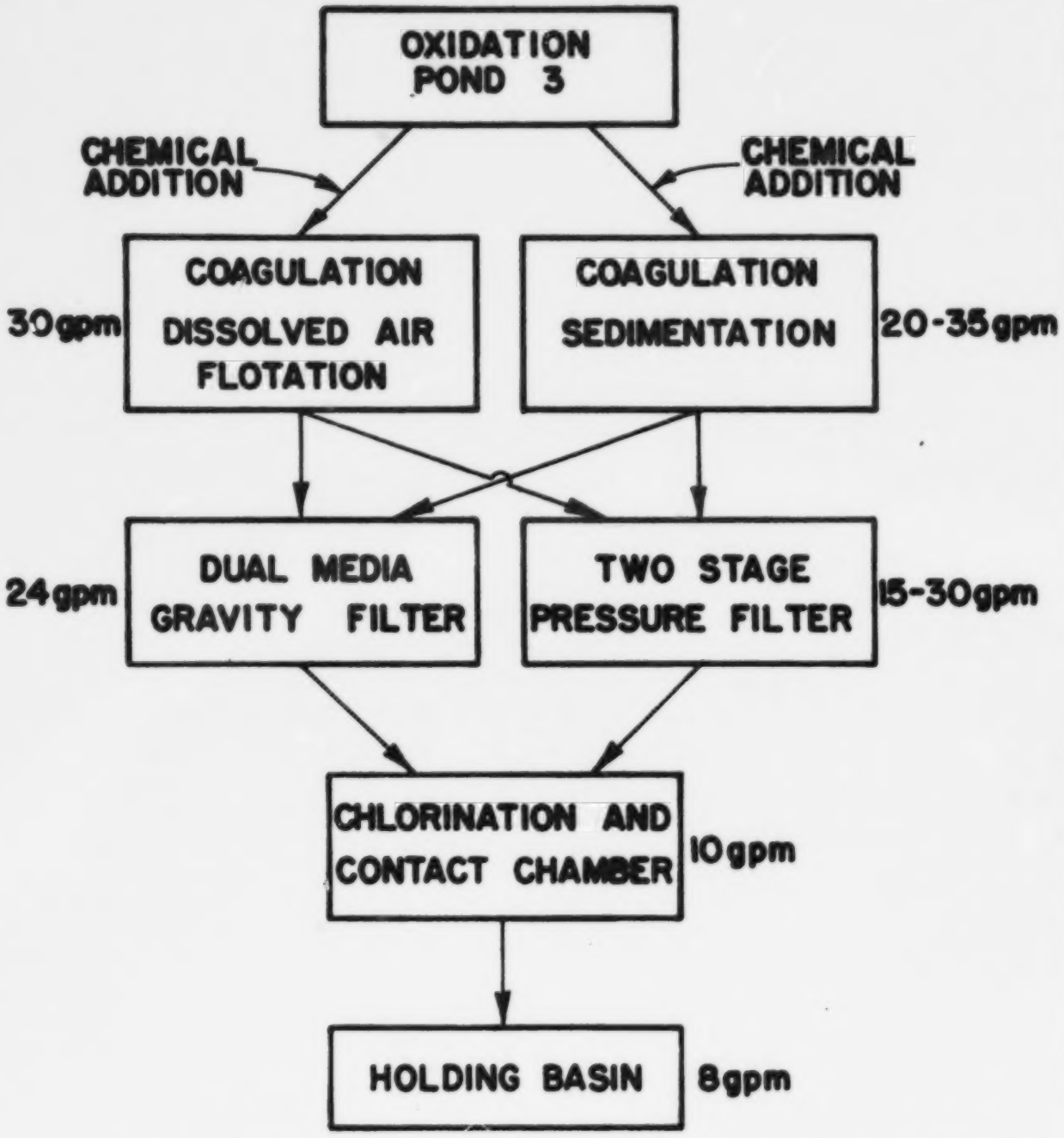
A. Operation of the Preferred Process

It was concluded from the pilot studies that the combined processes to accomplish the quality objectives at least cost was: (a) Alum coagulation, (b) either dissolved air flotation or plain sedimentation, (c) either pressure

sand or dual media gravity filtration, and (d) chlorination (Figure 10). These processes were arranged in combinations and automated sufficiently to permit their 24-hr per day operation while being attended only 8 hr. per day. The processes were operated for a full year with the product water being monitored and fed to a small simulated lake in order to demonstrate the continuous production of high quality water, to compare the alternative chemical treatment and filtration processes for reliability at all times of the year, and to evaluate the behavior of the product water in the simulated lake.

The horizontal flow sedimentation unit was designed for 20 to 50 GPM at overflow rates between 300 and 700 GPD/ft^2. The effluent was removed by a submerged launder to avoid floc that might float to the surface. This feature was found to be unnecessary since there was almost no floating floc in a year of operation. A mechanical scraper removed the settled sludge.

Although there was almost no difference in quality characteristics during a year of comparative operation, the sedimentation and dual media gravity filtration systems were selected over the flotation and pressure sand filter systems on the subjective basis of simplicity of operation and general reliability. Alum dosages were increased to 300 mg/l during the evaluation study to reduce phosphate to its lowest practical minimum. As later tests established, algae growth is not noticeably inhibited at phosphate concentrations above 0.5 mg/l.



CONTINUOUS PILOT PLANT FLOW SHEET
PHASE II

FIGURE 10

Figure 11 shows the residual turbidity as a function of aluminum sulfate dosage for pilot plant air flotation and horizontal sedimentation tests averaged over the Phase I and Phase II study. Figure 12, shows the residual phosphate as a function of alum dosage for pilot plant tests conducted in the Phase I and Phase II study, and averaged for the high alkalinity-high phosphate and low alkalinity-low phosphate periods. These results show the effectiveness of increasing the alum dosage to 300 mg/l or more to meet both the turbidity and total phosphate quality criteria for the recreational lake water.

The process chosen for converting the oxidation pond water for use in recreational lakes features:

a. Coagulation with approximately 300 mg/l of commercial grade aluminum sulfate and 20 minutes of flocculation with a typical water treatment plant paddle flocculator.

b. Sedimentation with an overflow rate of about 400 GPD/ft^2 in a horizontal flow tank equipped with sludge scrapers. The sedimentation tank will be covered to prevent wind-generated currents and turbulence.

c. Filtration through a dual media gravity filter comprised of 18 in. of 0.5-mm anthracite over 8 in. of No. 20 sand.

d. Chlorination at about 6 to 15 mg/l. Chlorine may be added prior to the sedimentation tank (to reduce crustacean populations reaching the filter) or after the filtration step.

RESIDUAL TURBIDITY vs. ALUMINUM SULFATE PRIOR TO FILTRATION

PILOT PLANT

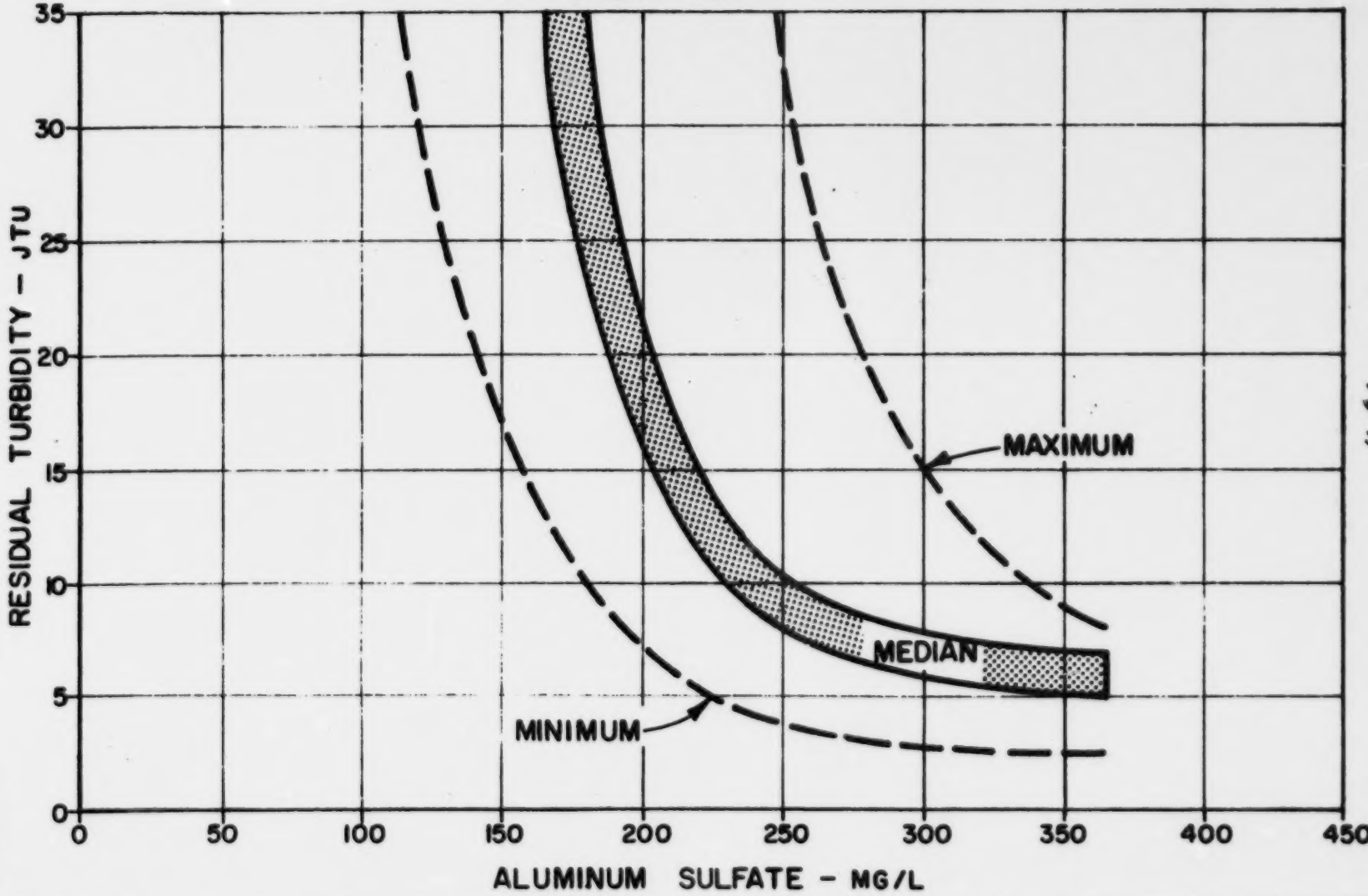


FIGURE 11

18-B

RESIDUAL PHOSPHATE vs. ALUMINUM SULFATE PRIOR TO FILTRATION

PILOT PLANT

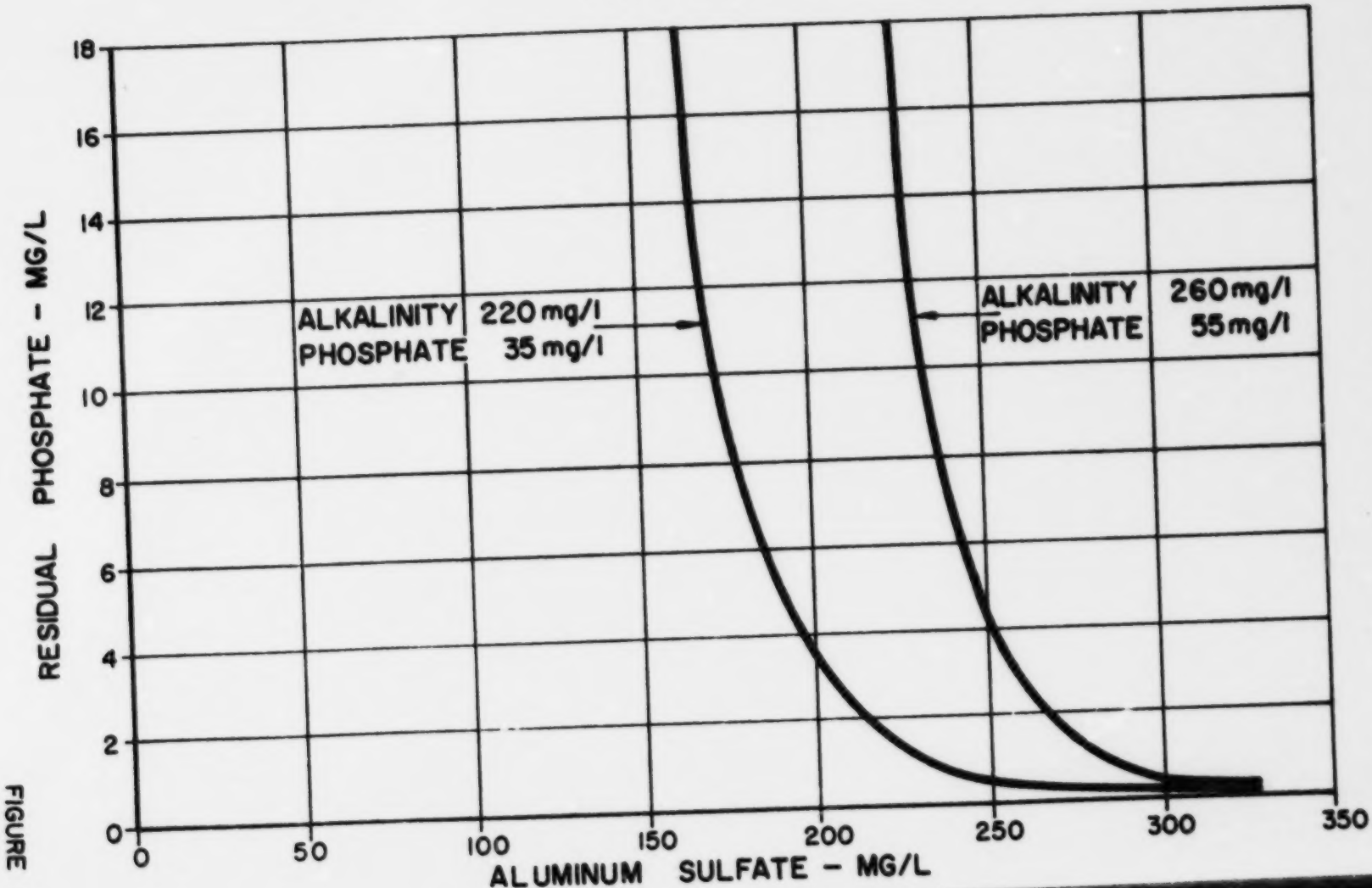


FIGURE 12

18-B

e. Minimum 8-hr. retention in a chlorine contact chamber.

f. Skimmings and sludge from the sedimentation tank and backwash water from the filter will be returned to the inlet of the plant. Most solids will be removed with the primary sludge and digested.

The characteristics of the processed water are compared with those of pond 3 water in Table 1. A 500,000 GPD facility is being designed to supply the 19-acre recreational lakes. This will prevent dissolved solids in the lake from increasing beyond 700 mg/l due to evaporation. The water will also be used to irrigate the surrounding park. The capital cost of the plant is estimated at about $150,000. Operating costs are estimated at $184 per million gallons of which chemical costs comprise $70 per million gallons. When expanded to 3 MGD capacity, the total cost of capital, operation and maintenance is estimated at about $150 per million gallons compared to about $200 per million gallons for imported water.

B. Holding Basin Studies

Holding basins were constructed to simulate the recreational lake environment. The objectives were: evaluation of the process water quality criteria, determination of the chemical and biological behavior of the water, determination of the tolerance of fish for the water, and testing of controlling auxiliary methods of algal regrowth. Selected laboratory tests were also conducted on processed water to determine the relationship between phosphate concentration and algae regrowth.

TABLE 1

COMPARISON OF POND 3 AND

PROCESSED WATER CHARACTERISTICS

Characteristics	Pond 3 Water	Product Water
pH	8.3	6.7
Turbidity (JTU)	90	4
Total Alkalinity (mg/l as $CaCO_3$)	260	95
Hardness (mg/l as $CaCO_3$)	80	100
Suspended Solids (mg/l)	75	6
Dissolved Solids (mg/l)	575	575
Chemical Oxygen Demand (mg/l)	250	50
Biological Oxygen Demand (mg/l)	38	< 10
Dissolved Oxygen (mg/l)	0.1 to 40	7 - 15
Ammonia-N (mg/l)	0.1 - 20	0.1 - 20
Organic - N (mg/l)	7 - 20	1 - 3
Nitrate - N (mg/l)	1 - 4	1 - 4
Nitrite - N (mg/l)	0.1 - 12	0.1 - 12
Total - Nitrogen (mg/l)	7 - 20	3 - 20
ABS mg/l	3	3
Phosphate (mg/l)	40	0.25
Algae (Counts/ml)	200,000	7,000
Confirmed Coliform (MPN/100 ml)	7,900	< 1.8
Chlorine Residual mg/l	-	0.2 - 0.5

Three different sized basins were used: (a) several 1500-gal. 7.5 ft. diameter, 3.5-ft. deep rubber tanks, (b) two 10,000 gal., 4-ft. maximum depth concrete-lined ponds, and (c) an unlined 250,000 gal. 10-ft. deep simulated lake.

C. Batch Tests

During the initial stages of the pilot program, several batch test evaluations of the treated water were conducted in 1500-gal. rubber tanks. Alum and lime were used in several concentrations such that the product water contained between 1 and 5 mg/l phosphate. Extensive regrowth occurred in each case within 2 months. Concentrations of chlorella and Ankistrodesmus reached 600,000 cells/ml.

In another experiment phosphate was reduced to 0.2 mg/l with 300 mg/l of alum and the water divided between two 1500 gallon tanks. Dipotassium phosphate was added to one tank to raise the phosphate concentration to 56 mg/l. Regrowth of algae was greatly retarded in the low phosphate water although, after 6 weeks, both test basins had similar cell counts, turbidity, and appearance. The high-phosphate water produced a great deal more algae in the same time period and accumulated a significant sludge deposit of dead algae on the tank bottom. This would not necessarily influence the actual concentrations of algae to be expected in the recreational lakes but would mean that rates of algae production would be significantly inhibited. As a consequence there should be fewer maintenance problems in the lake due to sludge accumulations and the lake environment should be more suitable for fish.

D. Draw and Fill Tests

A long-term experiment consisted of adding alum - treated water with low turbidity and phosphate, to the 10,000-gal. pond to maintain about a 40-day detention period. All of the water was filtered and some of it chlorinated. Alum doses varied between 200 and 300 mg/l. Eight month's data are averaged in Table 2(1)a for the period between November 1964 and June 1965. Generally pH values which were between 6.5 and 7.5 for the treated water entering the basin rose to pH 9 and phosphate was within the 2 mg/l maximum phosphate quality criteria initially set. The pH rise probably resulted from algae fixing CO_2 and HCO_3 from the water. The water also contained COD and algae concentrations similar to or greater than pond 3. The dissolved oxygen concentration never reached the intolerably low values observed in pond 3.

Several other proposed methods of controlling algae regrowth were tested. Lampblack and powdered activated carbon were used without success. In theory, the carbon would adsorb sunlight and prevent light penetration to the algae. However, the carbon failed to stay suspended in the water for more than a few days and no growth inhibition was noticed. Crustaceans were placed in the water, and on two occasions, when the pH was lowered with acid to pH 7, blooms of rotifiers and crustaceans consumed nearly all the algae; but the crustaceans died and algae growth eventually resumed. Chlorination up to 10 mg/l is not effective in reducing algae concentrations for more than a few days. Organic algicides and copper compounds controlled certain algae species but they were not effective for all types of algae. Furthermore, they are not effective for any significant time when used at concentrations that would not be harmful to fish.

TABLE 2

COMPARISON OF WATER CHARACTERISTICS IN HOLDING BASINS

OBSERVATION PERIOD	WATER TEMP - °C	pH	PHOSPHATE MG/L	ALGAE COUNTS 10^3/ml	PREDOMINANT ALGAE GENERA
(1) 10,000 GALLON HOLDING BASIN					
a) PILOT PLANT PROCESS EVALUATION					
11/64 to 6/65	11	9.0	0.73	926	CLOSTERIDIUM & SCENEDESMUS
b) CONTINUOUS PILOT PLANT EVALUATION					
9/65 to 4/66	13	8.9	0.12	247	OSCILLATORIA, SCENEDESMUS, NITZSCHIA, & NANNOCHLORIS COCCOIDES
(2) 250,000 GALLON HOLDING BASIN					
9/65 to 4/66	15	8.8	<0.05	~2400	NANNOCHLORIS COCCOIDES

21.14

All of these studies were conducted during the pilot process evaluations when it was still uncertain whether phosphate control could be used to prevent objectional algae growths in the recreational lakes.

In July of 1965, the pilot plant began operating continuously and at higher alum dosages. Chemical data for the 10,000 gal. concrete lined basin are summarized in Table 2(1)b for the period between September 1965, and April 1966. Comparison of these data with 2(1)a shows that the use of 300 mg/l alum reduced phosphate residuals by a factor of 5 and algae counts by a factor between 3 and 4. The predominant algae genera at times changed from the typical green algae usually associated with polluted water, i.e., Scenedesmus, Closteridum, etc. to Nannochlonis Coccoides Naumann a very small green algae that has never been observed in polluted water.

The effect of low phosphate residuals was even more striking in the 250,000 gal. unlined basin for which chemical and algae data are presented in Table 2(2). Nannchloris coccoides Naumann was the most prominent and often the only algae genera observed. Due to the extremely small size of Nannochloris cocoides, algae counts in the basin did not equal the weight of organic matter in oxidation pond 3 which averaged about 200,000 counts/ml. The dissolved oxygen levels in this and the smaller 10,000-gal. basin were at least 5 mg/l or more throughout a year of operation, and the diurnal dissolved oxygen changes were minor compared to those in pond 3.

Algae will strip most of the remaining orthophosphate from tertiary effluent. Total phosphate concentrations entering the basins averaged 0.25 to 0.3 mg/l, but concentrations in the lakes stayed below 0.05 mg/l. Algae used the phosphate, then settled to the bottom where the phosphate was unavailable. However, extensive decomposition of the sludge layer might cause a sharp increase in phosphate concentration. Low phosphate concentrations (70.5 mg/l) limited growth in both holding basins during the continuous pilot plant preferred process studies in which approximately 300 mg/l alum was used.

Laboratory studies were also conducted to determine if the reduction in phosphate in the pilot plant was in fact inhibiting algae growth. Samples of product water were injected with varying concentrations of phosphate and of certain other micronutrients* known to be essential for algae growth. The samples were exposed to continuous flourescent lighting and stirred with a "wrist action" shaker. The tests showed that: (a) some algae growth occurred at phosphate concentrations as low as 0.05 mg/l, (b) phosphate concentrations of 0.1 to 0.3 mg/l significantly inhibited effect on the rate and density of algae growth, (c) phosphate concentrations below 0.5 mg/l inhibited algae growth and (d) phosphate concentrations between 1 and 30 mg/l supported about the same amount of

*Hutner's Micronutrient solutions were used. The complete solution added 0.76 mg/l zinc, 0.2 mg/l boron, 0.14 mg/l manganese, 0.03 mg/l iron, 0.04 mg/l copper, 0.06 mg/l molybendum and 1.75 mg/l EDTA (Ethyldiaminetetraacetic acid). Other solutions with one or more nutrients left out were also used.

algae growth. To inhibit algae growth entirely would probably require removal of phosphate to concentrations well below 0.05 mg/l in the product water. Such removal is economically unfeasible and appears unnecessary because of the apparent suitability of the treated water for the recreational lakes.

E. Fish Survival Tests

Approximately 125 game fish (25 bass, 50 bluegill and 50 catfish) were placed in the 10,000-gal. and 250,000-gal. basins for observation. Some 700 Gambusia or mosquito fish and 20 fathead minnows were also added to provide food for the larger game fish. About 90% of the fish are still active in the ponds. Few fish were lost on four different occasions because of specific, but unrelated causes.

Several fish died when the chlorine residual increased from 0.2 to 1.5 mg/l in the 250,000-gal. basin. Rising ammonia concentrations in December had eliminated free chlorine residuals and the dosage was increased to 12 to 15 mg/l to maintain bactericidal control with the less effective chloramines. The chloramines were so stable, however, that they were not utilized by other organics in the large holding basin. Reduction of the chlorine dose resulted in recovery of the remaining fish.

Again during the colder season, another effect of high ammonia concentrations was observed when the ammonia reached 8 mg/l and the fish began to exhibit signs of distress. The high ammonia concentration coincided with a rise in pH apparently related to increased algal activity

as water temperatures were also climbing. At higher pH's, the percentage of ammonia in the form of ammonium hydroxide increases substantially and apparently becomes a toxic agent to fish. This problem can be circumvented in the proposed 0.5 MGD tertiary treatment plant by selective storage and withdrawal of water low in ammonia. The ammonia entering the oxidation ponds is readily converted to other nitrogen compounds during periods of warm weather. With an average detention time of 45 to 60 days between the inlet of the oxidation ponds and the point of withdrawal to the tertiary process, ammonia levels do not rise substantially in pond 3 until some time around December. By April, rising water temperatures cause a sudden drop in ammonia concentrations throughout the oxidation ponds. By filling oxidation pond 3 to capacity prior to the rise in ammonia concentrations and then bypassing around it during the winter, there will be low ammonia content water for the recreational lakes throughout the year.

During the latter part of the cold season in 1966, the dissolved oxygen level fell below 3.5 mg/l throughout the 250,000-gal. simulated lake. The water had a brownish appearance and algae counts decreased to 50,000 cells/ml. Some fish were in distress. Artificial aeration was provided and the dissolved oxygen level increased to saturation within 3 days. It is theorized that the brownish color was caused by a bacterial bloom that used up more oxygen than was being produced by the few algae present. This experience emphasized that any

biological system is subject to unpredictable changes and that blooms of bacteria, crustaceans or algae may result in occasional oxygen depletion in any recreational lake using reclaimed water. It is therefore recommended that some method for supplementing the oxygen content of recreation lake water be provided for emergency use.

IV. Conclusions

Turbidity, algae and phosphate reduction of conventional oxidation pond water can be economically achieved. A practical tertiary process has been developed to supply boating and fishing lakes near Lancaster, California. The process selected and piloted at 30 GPM features treatment with 200 to 300 mg/l alum, sedimentation, filtration, and chlorination. Phosphate is consistently reduced from 40 mg/l to less than 0.5 mg/l and algae counts from several hundred thousand to a few thousand per milliliter. Product water has been evaluated in the laboratory and in large simulated lakes stocked with fish. Algae grow to high concentrations slowly in the water but the rate of biological activity does not deplete the oxygen supply nor interfere with fish life, or cause nuisances. Laboratory stimulated growth tests show that algae growth rates are inhibited at phosphate concentrations less than 0.5 mg/l and almost stopped at less than 0.05 mg/l. The ecology of the simulated lake is typical of a fresh water environment supplied with limited nutrients.

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